Diagnostic and Interventional Imaging (2013) **94**, 1117—1121

ELSEVIER MASSON

& Interventional Imaging

ORIGINAL ARTICLE / *Technical*

Which dose for what image? Iterative reconstruction for CT scan

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KEYWORDS
CT scan;
Irradiation;
Iterative reconstruction;
Dose;
X-rays

Abstract

Purpose: To evaluate the potential of iterative reconstruction for reducing the dose given to the patient during abdominal CT scanning.

Materials and methods: A double abdominal CT scan acquisition (Somatom Definition AS+ Siemens) performed without contrast administration at −30% and at −70% of the doses (mAs) was compared to the standard acquisition in 10 patients. The raw data were reconstructed by filtered back projection (FBP) and using the SAFIRE iterative reconstruction method (five levels of iteration). The signal, noise, signal-to-noise ratio (SNR) and the contrast-to-noise ratio (CNR) were compared for three regions of interest, including the kidney, psoas and abdominal fat.

Results: The signal in each region of interest was not modified based on the type of reconstruction. The noise level decreased significantly during the passage from the FBP to SAFIRE, as well as with the increase in the SAFIRE level. The SNR and CNR therefore increased with the use of iterative reconstructions. The increase in noise observed between the acquisition at −30% and that at −70% was compensated by the use of higher SAFIRE levels.

Conclusion: Iterative reconstructions can be used to improve the SNR and CNR at a constant dose or to reduce the dose by keeping the same SNR and CNR on abdominal CT images.

The basic principle for obtaining images by CT scan is based on the determination of attenuation coefficients (μ) of the different tissues that are crossed [1]. To each pixel that makes up the final image, a level of gray corresponding to the μ is attributed using the Hounsfield scale. To determine and differentiate these μ, the tube/detector couple turns around the patient. The signal recovered in the detectors for a CT scan image thickness,

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2211-5684/$ — see front matter
http://dx.doi.org/10.1016/j.diii.2013.03.008

at a given angle, corresponds to a projection. For each CT image, all of the projections obtained for the different angles correspond to a sinogram of the CT image. In order to obtain an image that is as close as possible to the real object, all of the sinograms of the explored volume are sent to calculators to reconstruct the images. The simplest reconstruction method is retroprojection. It makes it possible to go from the signal of the projections, the Radon space, to the spatial domain corresponding to the image. It consists of spreading the signal of each projection in all of the pixels, which make up the image. This technique leads to the appearance of a blur, characterized by a star-shaped spreading artifact, causing a loss of information for high frequencies. To compensate for this artifact, filtered back projection (FBP), a fast reconstruction method available in all CT scan machines, is used. This method uses the application of different convolution filters in the real space. The difference between these filters is the variation in noise and spatial resolution. The more the filter is called ''hard'', the more the spatial resolution increases and the more the noise in the image is amplified. This process is inversed for filters that are called ''soft''. These different filters are applied based on the explored anatomical regions or the diagnosis being screened for. However, FBP, which is currently the most commonly used reconstruction method for CT scan, has drawbacks. Many approximations are unverified in practice, due to the absence of taking into account statistical fluctuations and physical disturbances. The data obtained are noisy and under-sampled.

The iterative reconstruction method, which is the reference method in nuclear medicine for the reconstruction of images, is starting to reappear with CT scans. These reconstructions were possible in nuclear medicine or with the first CT scan machines because the data were less voluminous to process with the calculators. With the improvement of performances of computerized tools as well as the prior reconstruction of data acquired by FBP, the data calculation time, in principle, no longer poses a problem for CT scans with the currently marketed solutions. This reconstruction method is based on the idea of the sinogram, like for FBP [2,3]. Unlike FBP, it takes into account statistical fluctuations and physical disturbances. The iterative algorithms allow for better quantitative estimation. They work by successive approximations to determine the solution that is the closest to the real object. At each iteration, a new estimation of the CT image is performed. Unlike FBP, iterative reconstruction allows us to separate noise and spatial resolution. It improves spatial resolution in the zones where the contrasts are highest, and reduces noise in the zones with low contrast, which makes it possible for the user to carry out scans with lower dose levels or to obtain a better image quality with the same radiation. Their disadvantage for the radiologist is the modification of the image in terms of the visual result related to the smoothing of the images. Each manufacturer offers algorithms that vary by their use and the way they function. Certain reconstruction algorithms use iteration loops in the raw data domain, others in the image domain, and finally others use iteration loops in both domains. Siemens with Sinogram Affirmed Iterative Reconstruction (SAFIRE) and Philips with iDose^4 (iterative Dose) are presented in the form of iteration levels. Adaptive Statistical Iterative Reconstruction (ASIR) by General Electric applies a percentage of the iterative method compared to filtered back projection. Finally, Toshiba markets Adaptative Iteration Dose Reduction (AIDR), which works by automatic setting and AIDR 3D, which offers three levels of selection: strong, mild and standard.

The objective of our evaluation was to study the influence of an iterative reconstitution method on the signal, noise, signal-to-noise ratio (SNR) and contrast-to-noise ratio (CNR) in the image so as to consider dose reductions for future scan acquisitions.

Materials and methods

With a SIEMENS SOMATOM Definition AS+ scanner, composed of a 64-detector bar, the proposed iterative reconstruction method is called SAFIRE (Fig. 1). This method is an improvement on the previous version, IRIS ''Iterative Reconstruction Image Space'' and has two correction loops. A first correction loop is made in the raw data space. Using the FBP reconstructed image of the measured projections, a ''ray tracing'' is applied. This is the ''re-projection'' step. New projections are calculated using the reconstructed image. The differences between the measured projections and the calculated projections allow us to obtain a new sinogram that corresponds to the corrected image. A second correction loop is applied in the image space. The corrected image from the first loop is re-projected. The projections obtained are then corrected using successive iterations that update the image. The noise and the artefacts are reduced by correction of the geometric imperfections of the initial reconstruction. The loop ends when the level of noise of the obtained image corresponds to that of the level of the selected iteration. The SAFIRE system has five levels of iterations that differ in the selection of the filtering intensity. The higher the SAFIRE level, the smoother the image and the lower the noise in the image. No clinically significant difference in acquisition time has been observed between the different levels of iterations in the reconstruction of CT scan examinations.

In order to check the impact of the iterative reconstructions and whether or not they could be put to regular use, ten patients who needed to undergo an abdominal-pelvic CT scan examination were studied with a double abdominal acquisition without injection and without extra radiation compared to the usual acquisition protocol. Using the scoutview, a double sequence was carried out wherein only the mAs was changed as an acquisition parameter. The first sequence was acquired with a number of mAs reduced by 30% (180 mAs to 125 mAs) and the second acquisition with a reduction in mAs of 70% (180 mAs to 54 mAs). The doses received by the patients were then almost equivalent to the one proposed initially. The raw data of the two acquisitions was then reconstructed with the FBP and the five levels of SAFIRE (S1, S2, S3, S4 and S5) and an average filter (B40f or I40f). The regions of interest (ROI) were positioned on the left kidney, the psoas muscle and the fat to study the signal obtained (Fig. 2). The evaluation of the CNR was carried

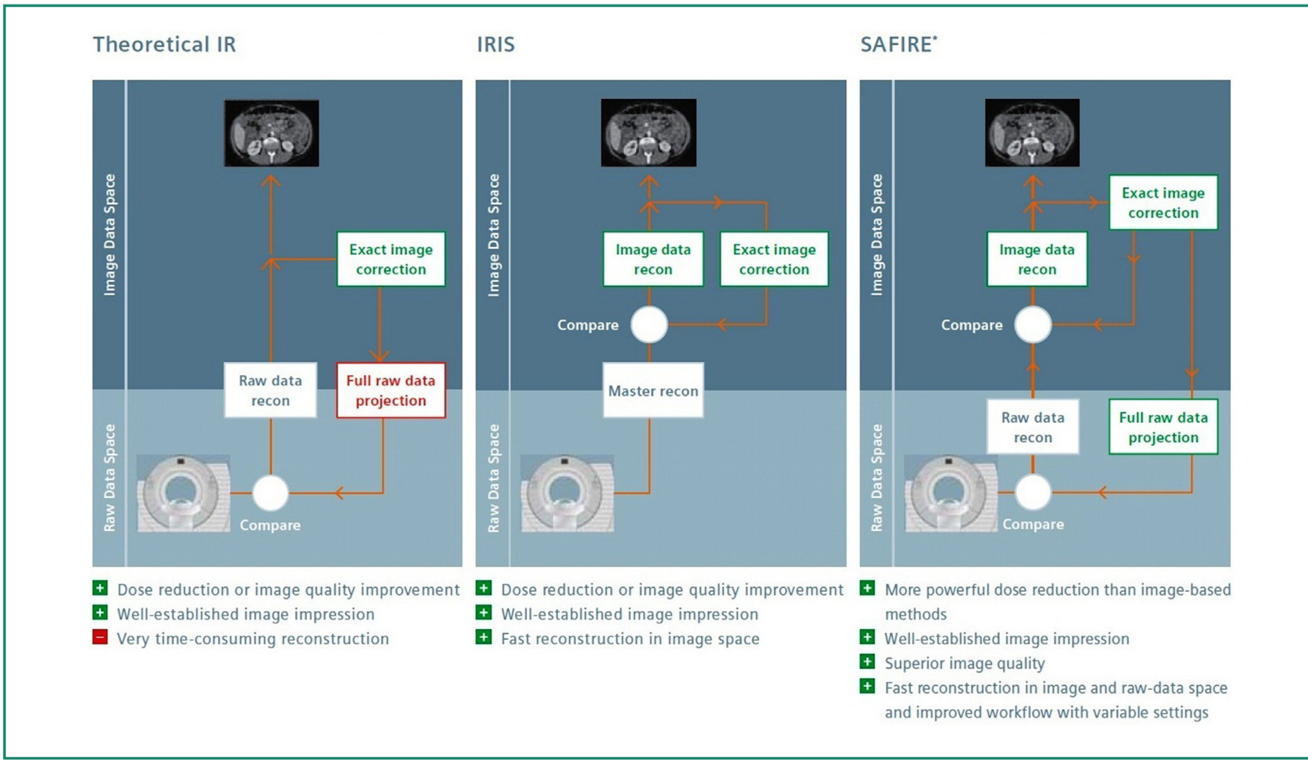

Figure 1. Sinogram Affirmed Iterative Reconstruction (SAFIRE) iterative reconstruction method, using two correction loops in the raw data and image data spaces. It ends when the noise level of the image obtained corresponds to that of the selected iteration level (with kind permission of Siemens).

out using a reference region of interest positioned on the abdominal aorta (formula below):

$$CNR = \frac{\left|HU_{\text{Region}} - HU_{\text{Abdominalaorta}}\right|}{\sqrt{\frac{Noise^2_{\text{Region}} + Noise^2_{\text{Abdominalaorta}}}{2}}}$$

(Determination of the contrast to noise ratio using regions of interest compared to the abdominal aorta).

Results

The column analysis in Table 1 shows that the signal is not modified between the FBP and the different SAFIRE levels for the three regions of interest, regardless of the dose. The passage from FBP to SAFIRE results in a decrease in noise in the three regions of interest for the acquisitions carried out. On average, the noise decreases by 11% between the FBP and S1. This reduction in noise is greater with the increase in iteration levels (12% between S1 and S2 and 18% between S4 and S5). As the signal was stable and the noise decreasing, the SNR increases the SAFIRE levels even more. The CNR is improved with the increase in the SAFIRE level.

The comparisons between the acquisitions of 30% and 70% dose reduction (4.99 mGy initially to 3.44 mGy for a 30% reduction in mAs and 1.52 mGy for 70%) from the reduction of mAs showed a considerable increase in noise in the image for the same level. The noise increased by 65% on average for the left kidney and 63% and 48% for the psoas muscle and fat, respectively. The signal for the same level is increased by 15% for the left kidney, although it remains constant for the psoas muscle and fat (2% variation). The SNR and CNR are decreased between the two acquisitions from 50 to 65% and 30 to 45%, respectively.

The comparative analysis between S2 at 30% and S5 at 70% shows that the results of the signal, noise, SNR and CNR are relatively equivalent regardless of the region of interest. The 70% S5 reconstructions allowed us to obtain images that were equivalent in signal, noise, SNR and CNR compared to 30% S2 for a reduction of 1.92 mGy of the CTDIvol.

These data are found in the images of Fig. 2, with a visual difference related to the smoothing of the image. This smoothing of the image is observed when the SAFIRE levels are increased, which is a characteristic that is specific to iterative reconstruction methods.

Discussion

This first approach for the evaluation of SAFIRE iterative reconstructions highlights two points of interest of these iterative reconstruction methods, that is to say, both qualitative and quantitative. The first point of interest is that we are be able to reduce the noise of the image for the same administered dose. The SNR and CNR are therefore improved with the increase in SAFIRE levels. The second point of interest is that we are be able to reduce the emitted X-ray dose, particularly mAs [4], while keeping the SNR and CNR stable. The increase in noise caused by the reduction of mAs is compensated for in the image by a higher SAFIRE level. The results of the 10 patients show that the decrease in

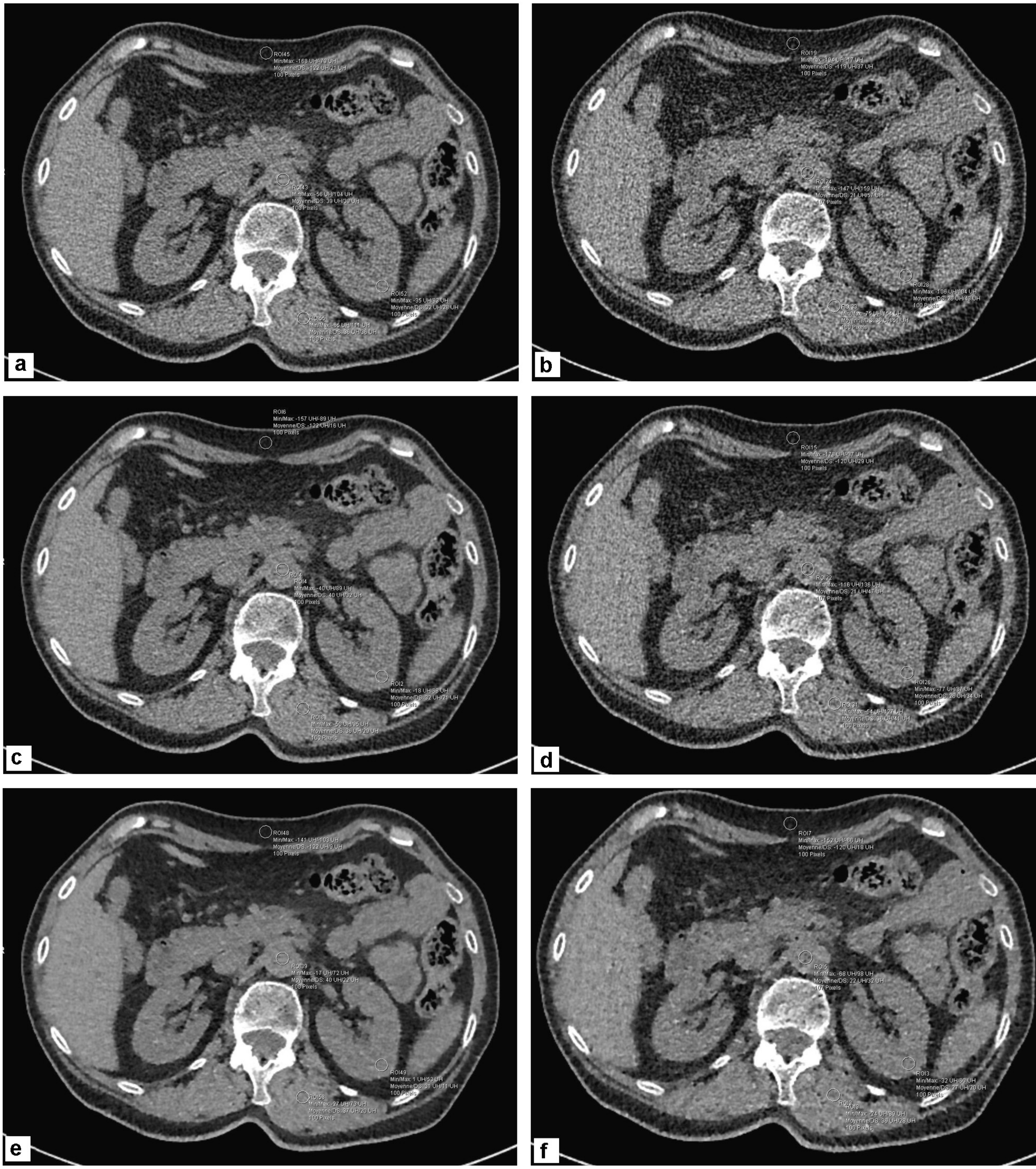

Figure 2. Transverse axial CT image in filtered back projection (FBP), S2 and S5 of a patient for the acquisitions with 30% (a, c, e) and 70% (b, d, f) dose reductions, with 4 regions of interest on the left kidney, the abdominal aorta, the fat and the psoas muscle. Visualization of the smoothing of the image with an increase in the Sinogram Affirmed Iterative Reconstruction (SAFIRE) level. The signal, noise, signal to noise ratio (SNR) and contrast to noise ratio (CNR) are equivalent between S2 at 30% (c) and S5 at 70% (f).

noise is confirmed with the increase in SAFIRE level. The quality of the image obtained with a 30% dose reduction is very close to the images that are generally obtained. With the acquisition at a 70% dose reduction, the image is noisy at low SAFIRE levels. However, the SNR and CNR can be improved by using higher iteration levels. Therefore, the level of noise, SNR and CNR in the three regions of interest for the reconstructed image with a 70% dose reduction in S5 correspond to those present in the image with a 30% dose reduction in S2. A degradation of the acquisition parameters causing a dose reduction is therefore compensated for by iterative reconstruction methods.

The recent availability of iterative reconstruction methods in CT scanning has a clinical utility that no longer needs

Table 1 Influence of iterative reconstructions on the image quality for the three regions of interest (ROI) with a 70% or 30% reduction in mAs at acquisition.

	HU		Noise		SNR		CNR	
Kidney (%)	30	70	30	70	30	70	30	70
FBP	27.4	32.2	31.7	49.7	0.92	0.71	0.44	0.26
S1	27.6	31.8	27.9	44.4	1.05	0.78	0.49	0.29
S2	27.6	31.8	24.4	39.4	1.20	0.88	0.55	0.31
S3	27.6	31.7	20.9	34.3	1.39	1.01	0.63	0.36
S4	27.7	31.6	17.3	29.4	1.67	1.18	0.76	0.39
S5	27.8	31.4	13.9	24.6	2.09	1.42	0.95	0.45
Psoas (%)	30	70	30	70	30	70	30	70
FBP	44.9	46.6	32.8	52.2	1.48	0.94	0.32	0.24
S1	45.0	46.4	28.9	46.9	1.69	1.05	0.36	0.25
S2	45.1	46.1	25.4	41.2	1.93	1.18	0.39	0.28
S3	45.2	45.9	22.0	35.8	2.23	1.36	0.44	0.31
S4	45.2	45.8	18.6	30.7	2.67	1.59	0.49	0.36
S5	45.6	45.7	15.1	25.6	3.35	1.91	0.60	0.42
Fat (%)	30	70	30	70	30	70	30	70
FBP	−111.7	−113.6	25.8	38.2	4.59	3.06	4.93	3.15
S1	−111.6	−113.6	22.8	34.0	5.21	3.44	5.56	3.52
S2	−111.4	−113.6	19.9	29.6	5.95	3.95	6.36	3.98
S3	−111.3	−113.4	17.1	25.3	6.93	4.60	7.32	4.57
S4	−111.2	−113.0	14.3	21.3	8.36	5.46	8.79	5.34
S5	−110.8	−112.9	11.9	17.1	10.19	6.85	10.83	6.39

30% represents a mAs reduction from 180 to 125, i.e. a dose reduction from 4.99 mGy to 3.44 mGy. 70% corresponds to a reduction from 180 to 54 mAs, i.e. a dose reduction from 4.99 mGy to 1.54 mGy. FBP is filtered back projection; S1 to S5 are iteration levels of the SAFIRE iterative reconstruction method; the noise and the signal in HU are values of the three regions of interest placed on the psoas muscle, the left kidney and the fat. The SNR is the signal to noise ratio. The CNR is the contrast to noise ratio, for which the abdominal aorta is the reference. The tension (100 kV), collimation (128×0.6 mm), pitch (0.8), reconstruction filter (B40f or I40f) and reconstruction thickness (2 mm/1 mm) were set for the two acquisitions.

to be demonstrated [5,6]. Using different image processing methods, iterative reconstruction algorithms make it possible to improve or maintain image quality with lower radiation. They cause a noise limitation, a reduction in artefacts in hyperdense structures, a conservation of spatial resolution or contrast while making it possible to administer a dose of rays that is far lower (between 40% and 60% depending on the anatomical region). However, more in depth studies must be conducted to quantify the impact of the smoothing of the image between the SAFIRE levels on the spatial resolution and the quality of the diagnosis.

Disclosure of interest

The authors declare that they have no conflicts of interest concerning this article.

Acknowledgments

We would like to thank Mr. Adrian Gomez and Mr. Cédric Croisille, Siemens engineers who actively participated in improving our knowledge concerning iterative reconstructions.

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